THE CONTRIBUTION OF MARINAS TO FECAL INDICATOR BACTERIA IMPAIRMENT IN LOWER NEWPORT BAY, SOUTHERN CALIFORNIA

A report prepared for the City of Newport Beach and the Santa Ana Regional Water Quality Control Board by

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Executive Summary

The development and implementation of Total Maximum Daily Load (TMDL) management plans requires, at a minimum, the identification of pollution sources likely to be responsible for water quality impairment. *The objective of this study is to investigate the contribution of marinas to fecal indicator bacteria (**FIB**) impairment in Lower Newport Bay, Orange County, southern California.* To achieve this objective, five separate field experiments were carried out at two different marinas in Lower Newport Bay: a City owned marina called the Balboa Yacht Basin (**BYB**), and a County owned, privately operated marina called the Dunes Marina (**Dunes**). The two marinas differ in size (BYB marina has 174 boat slips, Dunes has 450 boat slips), shape (notched versus flow-through) and (presumably) tidal flushing characteristics. Three different categories of data were collected and correlated: (1) current meter data, (2) FIB data in the water column, and (3) FIB data in the sediments. The results of the data collection effort are summarized below in a Question and Answer format.

__Question__: How are currents, temperature, and salinity in the channels outside of the BYB and Dunes marinas affected by the tides?
__Answer__: In all four deployments of the S4 instrument, currents in the channels outside of the BYB and Dunes marinas were strongly forced by the tides. With one exception (the first Dunes study), salinity and temperature also exhibited a strong tidal signature. In general, during rising tides, currents are directed inland (in a westerly direction at the BYB site and in an easterly direction at the Dunes site) and bring with them colder and higher salinity water from the ocean. During falling tides, currents are directed oceanward (in an easterly direction at the BYB site and in a westerly direction at the Dunes site) and bring with them warmer and lower salinity water from Upper Bay. These data indicate that water quality impairment at the BYB and Dunes marinas could be influenced by a myriad of pollution sources located both inland and oceanward of the marinas.

__Question__: How are fecal indicator bacteria in the water column of the BYB and Dunes marinas (and surrounding channels) distributed in space? Are fecal indicator bacteria in the water column consistently higher in certain regions of the monitoring grid? Are these spatial and temporal patterns consistent across all five studies?
__Answer__: The fecal indicator bacteria signal exhibits relatively little site-to-site variability, but very large study-to-study variability. The highest bacterial concentrations were observed during the second Dunes study; approximately 10% of the samples collected during this study exceeded the single-sample standard for ENT. Fecal indicator bacteria concentrations were strongly negatively correlated with salinity during the second Dunes study. Weaker negative correlation were also evident in several other cases, including at sampling sites located in front of storm drains. Overall, these results are inconsistent with the idea that vessel discharges in the BYB and Dunes marinas are the primary sources of fecal indicator bacteria impairment in Newport Bay. Instead, the results point to surface water runoff (both dry weather runoff at sites in front of storm drains and wet weather runoff at all sites) as a significant source of fecal indicator bacteria impairment in Newport Bay.

Question: *How are fecal indicator bacteria in the sediment of the BYB and Dunes marinas (and surrounding areas) distributed in space? How do the sediment concentrations compare with the concentration of bacteria in water just above the sediment bed? Are the sediments a reservoir, and perhaps even a source, of fecal indicator bacteria in Newport Bay?*

Answer: *The concentration of fecal indicator bacteria in sediments exhibits relatively little site-to-site variability, but significant study-to-study variability. The highest sediment concentrations were observed during the second Dunes study which, as described earlier, also had anamolously high bacterial concentrations in the water column. During the second Dunes study, the concentration of fecal indicator bacteria in the sediment was so high that resuspension of sediments, for example by tidal flow, could have contributed to contamination of the water column. However, several lines of evidence indicate that the sediments are a net sink, not source, of fecal indicator bacteria in Newport Bay.*

I. Background and Objectives

Newport Bay (Bay) is the second largest estuarine embayment in southern California. The Bay provides a critical natural habitat for terrestrial and aquatic species, and serves as a spawning and nursery habitat for commercial and non-commercial fish species. The Lower Bay is a regionally important recreational area, and one of the largest pleasure craft harbors in the United States. The Upper Bay is a state ecological reserve and provides refuge, foraging areas, and breeding grounds for a number of threatened and endangered species. Beneficial uses of the Bay are threatened by numerous sources of pollutant loading that discharge into the Bay either directly, or via tributaries of its watershed. To reduce water quality impairments in the Bay, the Environmental Protection Agency and Santa Ana Regional Water Quality Control Board have adopted Total Maximum Daily Loads (**TMDLs**) for fecal coliform, nutrients, sediment, and toxic pollutants.

*The objective of this study is to investigate the contribution of marinas to fecal indicator bacteria (**FIB**) impairment in Lower Newport Bay.[1]*

To achieve this objective, five separate field experiments were carried out at two different marinas in Lower Newport Bay: a City owned marina called the Balboa Yacht Basin (**BYB**), and a County owned, privately operated marina called the Dunes Marina (**Dunes**). The two marinas also differ with respect to their size (BYB marina has 174 boat slips, Dunes has 450 boat slips) shape and, presumably, their tidal flushing characteristics. This report describes the experimental design utilized for the BYB and Dunes studies, the results obtained, and implications relative to the Newport Bay fecal coliform TMDL.

II. Experimental Design

II.A. Overview.

Since FIB concentrations are known to vary almost continually (Boehm et al., 2002; Boehm et al., 2003; Kim and Grant, 2004; Reeves et al., 2004; Kim et al. 2004; Grant et al., submitted), the study was designed to address the following issues:

- reproducibility
- comparison to water quality standards
- changes with depth
- high-use vs low-use seasons
- antecedent dry period
- tidal and diurnal changes
- water vs sediment FIB concentrations
- spatial variations, including identification of hot spots,
     proximity to storm drain, differences between marinas

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[1] The original intent of this study was to determine the bacterial contribution of vessels in Newport Bay (Task 7 –Evaluation of vessel waste program -Table 5-9g, Fecal Coliform TMDL). Since the bacterial contribution of vessel waste could not be isolated, a study was conducted to determine bacterial contribution of vessels by comparing marina vs channel samples, during high use and low use periods.

These experimental design issues are explored below.

Reproducibility
To evaluate the reproducibility of our sample collection and analysis procedures, duplicate samples were collected for approximately 10% of the water and sediment samples.

Comparison to Water Quality Standards
To compare results to water quality standards, exceedence frequencies, geometric means, and confidence intervals were computed from the FIB data collected at each sampling site.

Changes with Depth
To assess vertical stratification of FIB in the water column, paired water samples were collected from each site--one from the surface of the water column, and another from 1 m below the surface.

High-use vs. Low-use Seasons
Altogether, 4,125 water samples were collected from the BYB and Dunes marinas over a 14-month period of time, from July 2002 through September 2003 (see Table 1). Two studies were conducted during high-use periods (Dunes III was conducted over Labor Day weekend, and Dunes II was conducted over Easter Sunday weekend); the remaining studies were conducted during relatively low-use periods (Dunes I, BYB I, and BYB II).

Antecedent Dry Period
As indicated in Table 1, the antecedent dry period for these five studies varied considerably, from two days (for the Dunes II study) to 123 days (for the Dunes I study).

Tidal and Diurnal Changes
To capture tidal and day/night changes in the FIB signal, water samples were collected every three hours, twenty four hours per day, for the entire two to three day study period. In addition, a current meter was deployed in the channel outside of the marina (during the BYB I, BYB II, Dunes I, and Dunes II studies), so that tidal flow could be compared with FIB concentrations.

Water vs. Sediment FIB Concentrations
To assess the relative concentration of FIB in the water column and sediments, paired sediment and water samples were collected once daily from all sites during the Dunes II and Dunes III studies.

Spatial Variations, Identification of Hot Spots
To maximize the possibility of identifying hot-spots of FIB pollution, between 11 and 36 sites (depending on the study, see Table 1) were sampled. In the results presented later, these sampling sites were divided into three categories based on their location: (1) *marina samples*, collected from sites located within the marina being studied, and (2) *channel samples*, collected from sites located within the channel waters adjacent to the marina, (3)

storm drain impacted samples collected from sites in the marina or channel adjacent to storm drain outlets. The storm drain impacted samples were included in the BYB II and Dunes II and III studies; storm drain impacted sites were not sampled during the BYB I and Dunes I studies. The logic used to locate the sampling sites is described in the next section.

II.B. Site Selection and Residence Time Considerations.
The location of sampling sites within the BYB and Dunes marinas are indicated in Figure 1; the marina, storm drain impacted, and channel sampling sites are indicated by crosses, circles, and squares, respectively. The color of the symbols indicates the studies during which particular sites were sampled (see key in figure).

An important consideration of the experimental design was placement of the sampling sites inside, and outside, of the two marinas. Ideally, the sampling sites should be selected so that, after all of the data are collected and analyzed, FIB originating from sources within the marinas (e.g., from boat discharges) could be distinguished from FIB originating outside the marina (e.g., from surface water runoff entering Upper Newport Bay). This objective is more likely to be satisfied if FIB pollution events spend enough time in the sampling grid so that their direction of transport can be ascertained. This line of reasoning leads to the following constraint on the placement of the sampling sites:

Sampling sites should be arranged so that the residence time of water in the monitoring grid is significantly greater than the time interval between sampling events (T_S=3h, see above).

To satisfy this constraint, sampling sites were divided between within-marina locations (to detect the impact of illicit vessel discharges, if they occurred), and the channel outside of the marina area. Average current velocities of v_a =4-5 and 17-22 cm/s were measured with the S4 instrument in the channels outside of the BYB and Dunes marinas, respectively (see later discussion of current meter data).   Hence, to satisfy the constraint above, the sampling grids would ideally have a long dimension parallel to the peak tidal flow direction of at least 0.5 km ($= v_a T_s$) in the case of the BYB studies, and of at least 2.4 km in the case of the Dunes studies. The first constraint (0.5 km) was satisfied by distributing the sampling sites over a distance of 0.8 km in the channel outside of BYB. The second constraint (2.4 km) could not be satisfied in the case of the Dunes studies, because the geometry of the Bay places physical constraints on the distance that a sampling grid can extend into Upper and Lower Newport Bay. In the end, sampling sites in the channel outside of the Dunes marina were spread over a distance of 1.7 km, which is reasonably close to the constraint defined above (2.4 km).

Additional sites were added along the margins of the marinas and channel near storm drains outlets--*storm drain impacted samples*--during the BYB II, and the Dunes II and III studies. Storm drain impacted sites were added since storm drain outlets were noted in the marina walls during the first sampling events, and urban runoff is a known contributor of FIB. Additional sites were also sampled within a recreational lagoon located near the Dunes marina (during the Dunes II study). The recreational lagoon

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testing was added to supplement data collected for a swimmer shedding study conducted in the summer of 2002 (see Swimmer Shedding Report by Jiang et al).

II.C. Sample Collection and Analysis Protocols.
Water Column Samples
Water column samples were collected from a small (5m) boat powered by an outboard motor loaned to UCI by the City of Newport Beach. Sampling crews (consisting of 3 to 4 students) arrived at the field site every three hours, and then traversed the sampling grid in approximately one hour. At each sampling site, water samples were collected from the surface of the water column as follows. Sterilized Nalgene 500 mL bottles affixed to a sampling pole, lowered over the side of the boat, rinsed three times, and filled with surface water. A second 500 mL water sample was collected from 1 m below the water surface using a ball-valve sampling system affixed to a PVC pole. After the bottles were filled with water, they were capped and immediately placed on ice (in an ice chest) in the dark.

After the sampling run was complete, samples were off-loaded from the boat into a van, and transported to UCI for immediate analysis; all analyses occurred within 6 h from the time of collection. All samples were analyzed for FIB-- including total coliform (TC), *Escherichia coli* (EC, the major group of fecal coliform, FC), and enterococci bacteria (ENT)--using defined substrate tests known commercially as Colilert and Enterolert, implemented in a 97 well quantitray format. These particular tests were utilized because they are quantitative, relatively inexpensive, and not labor intensive. *E. coli* was tested in lieu of fecal coliform so that sampling could occur every 3 hours (fecal coliform analysis is time intensive and could not accommodate this sampling schedule). Also, the use of Colilert and Enterolert test kits made possible the processing of a large number of samples on a twenty-four hour per day basis. Samples were analyzed for a suite of physical parameters, including salinity, turbidity, and pH. Methods used for measuring these physical parameters can be found elsewhere (Reeves et al., 2004).

Sediment Samples and Above-Bed Water Samples
During two of the field studies (Dunes II and III), two sediment samples were collected once daily from the same set of sites where water samples were collected every three hours. In all, 115 sediment samples were collected and analyzed for FIB, including 55 during Dunes II and 60 during Dunes III. The sediment was collected in two 50 mL conical tubes (Fischer Scientific, Pittsburg, PA), affixed to the end of a telescoping pole. The pole was lowered over the side of a small boat, and the conical tube was forced into the bottom sediments to a depth of approximately 10 cm. The pole was then raised, and if the conical tube contained sediments it was capped and immediately placed on ice. If the conical tube did not contain sediments (e.g., due to wash-out of the sediments as the tube was raised through the water column), the entire procedure was repeated. This method worked well at most sites because of the soft (i.e., fine grained and organic rich) nature of bottom sediments in the Bay.

Immediately prior to sampling the sediment, a 500 mL water sample was collected from the bottom of the water column (just above the bed) using a ball-valve sampling system

affixed to a telescoping pole. The water and sediment samples were transported back to the laboratory in under 3h from the time of collection. Water samples were analyzed for FIB using the procedures described above, and sediment samples were processed as follows (Craig et al., 2002). Once the samples arrived at the laboratory, 25 g (wet weight) of the sediment sample was added to a 500 mL centrifuge bottle (Kendro Laboratories, Asheville, NC), resuspended in 75 mL of 0.1 % Peptone (Difco, Sparks, MD), hand shaken for 1 min., and then centrifuged at 500 rpm for 10 min. at 4-10 $^{\circ}$C using a GS 3 (max rpm 9000) rotor in a Sorvall RC28S Hybrid centrifuge (Dupont, Willmington, DE). The centrifuge bottles were then recovered, and 10 mL of the supernatant was collected and analyzed for FIB using the Colilert and Enterolert defined substrate tests, as described above. In order to report the concentration of FIB on a dry-weight basis, approximately 2 g of wet sediment was weighed out and dried overnight in an oven at 110 $^{\circ}$C and re-weighed. The sediment FIB concentration C_S was then calculated from the following formula:

$$C_S = \frac{C_t \, 75mL}{W_s r} \times 100 \text{ (units of MPN/100g dry sediment)} \tag{1}$$

where C_t is the concentration of FIB measured in the 10 mL of supernatant, W_s is the wet weight of sediment resuspended in the 0.1% peptone, and r is the dry-to-wet weight ratio for the sediment. A portion of each sediment sample was archived (at -70°C) to allow for future analyses (e.g., for grain size, TOC, and human viruses).

II.D. Data Reproducibility
To evaluate the reproducibility of our sample collection and analysis procedures, duplicate samples were collected for approximately 10% of the water and sediment samples. As an example of how this was carried out, during the first BYB study twenty-two water samples were collected from the field site every three hours, and hence two additional duplicate samples were collected per field run. The two sites at which the duplicate samples were collected varied with every field run to ensure that, by the end of the field project, duplicate samples had been collected at all sampling sites.

II.E. Current Meter Deployment.
To characterize the predominant tidal flow in the BYB and Dunes marina study areas, a multidirectional current meter with an integrated pressure transducer, thermister, and conductivity meter (S4, InterOcean Scientific) was deployed coincident with the BYB and Dunes sampling periods, with the exception of the Dunes III study for which the instrument was unavailable. The S4 was anchored by Orange County Sheriff Harbor Patrol divers to a bottom mounted mooring which positioned the instrument roughly 50 cm above the channel bottom. During BYB studies, the mooring was placed along the main channel east of BYB marina where the bed elevation was roughly -3.8 m (MSL); while during Dunes studies the mooring was placed along the main channel west of Dunes marina where the bed elevation is roughly -4.4 m MSL. Deployment locations are noted in Fig. 1 (designated as "S4"). During each deployment, the S4 was programmed to sample for current velocity, temperature, conductivity, and water level every 10 minutes

for a period of 2-3 weeks; only the portion of the data set coincident with the FIB measurements are reported here.

III. Results

III.A. S4 Measurements

__Question__: How are currents, temperature, and salinity in the channels outside of the BYB and Dunes marinas affected by the tides?
__Answer__: In all four deployments of the S4 instrument, currents in the channels outside of the BYB and Dunes marinas were strongly forced by the tides. With one exception (the first Dunes study), salinity and temperature also exhibited a strong tidal signature. In general, during rising tides, currents are directed inland (in a westerly direction at the BYB site and in an easterly direction at the Dunes site) and bring with them colder and higher salinity water from the ocean. During falling tides, currents are directed oceanward (in an easterly direction at the BYB site and in a westerly direction at the Dunes site) and bring with them warmer and lower salinity water from Upper Bay. These data indicate that water quality impairment at the BYB and Dunes marinas could be influenced by a myriad of pollution sources located both inland and oceanward of the marinas.

Time series plots of water level, salinity, temperature, easterly component of the current velocity, and the vertical velocity (computed by taking the time derivative of the water level measurements) are presented in Fig. 2. These data were recorded by an S4 instrument deployed in the channel outside of the BYB marina (during BYB I and II), and in the channel outside of the Dunes marina (during Dunes I and II). Tidal exchange of water between the ocean and the Bay causes the water level at the two study sites to rise and fall with the tides. The water level data have a semi-diurnal character (i.e., there are four distinct high and low tides per day--higher-high, lower-high, higher-low, and lower-low) during BYB I, BYB II and Dunes II studies, and a diurnal character (i.e., the higher-high and lower-high are about the same, as are the higher-low and lower-low) during the Dunes I study.

Dunes studies
Temperature and salinity recorded by the S4 instrument are strongly forced by the tides during the Dunes I and II studies, with salinity increasing and temperature decreasing during rising tides. This pattern suggests that relatively warm low-salinity water from Upper Bay flows past the Dunes site during ebb tides, and relatively cold high-salinity water from the ocean flows past the Dunes site during flood tides. Current velocities recorded during the first two Dunes studies are consistent with this interpretation. Specifically, the current records show that the flow of water in the channel outside of the Dunes marina was directed eastward during falling tides, and westward during rising tides (see the east-west orientation of the channel where the S4 was deployed, Fig. 1). The peak velocities recorded by the S4 are approximately 50 cm/s in the channel outside of the Dunes marina.

BYB studies
Salinity and temperature recorded in the channel outside of the BYB marina exhibit either no (BYB I) or moderate (BYB II) tidal signature. In the case of the BYB II study, the phasing of the salinity and temperature oscillations are the same as described above for the Dunes I and II studies. Specifically, salinity increases, and temperature decreases, during rising tides. The current velocity recorded in the channel outside of the BYB marina is directed westward during rising tides and eastward during falling tides--exactly opposite the pattern just described for the channel outside of the Dunes marina. Because of the sinuous nature of the Bay (see map in Fig. 1), during ebb tides water in the Bay flows in an easterly direction near the Dunes site and in a westerly direction near the BYB site. Peak tidal flow velocities in the channel outside of the BYB marina are approximately 10 cm/s.

The S4 data reveal that the temperature and salinity of water at the BYB and Dunes sites are, in general, influenced by tidal mixing of colder and higher salinity water from the ocean with warmer and lower salinity water from Upper Bay.

III. B. Observations of Water Column FIB Concentration
<u>*Question*</u>: *How are FIB in the water column of the BYB and Dunes marinas (and surrounding channels) distributed in space? Are FIB in the water column consistently higher in certain regions of the monitoring grid? Are these spatial and temporal patterns consistent across all five studies?*
<u>*Answer*</u>: *The FIB signal exhibits relatively little site-to-site variability, but very large study-to-study variability. The highest bacterial concentrations were observed during the second Dunes study; approximately 10% of the samples collected during this study exceeded the single-sample standard for ENT. FIB concentrations were strongly negatively correlated with salinity during the second Dunes study. Weaker negative correlation were also evident in several other cases, including at sampling sites located in front of storm drains. Overall, these results are inconsistent with the idea that vessel discharges in the BYB and Dunes marinas are the primary sources of FIB impairment in Newport Bay. Instead, the results point to surface water runoff (both dry weather runoff at sites in front of storm drains and wet weather runoff at all sites) as a significant source of FIB impairment in Newport Bay.*

Reproducibility
Measurements on the primary and duplicate samples are compared in Fig. 3. Each panel in the figure corresponds to a different analyte, including the concentration of FIB in the water column and sediment samples (upper left and upper right panels), pH (middle left panel), turbidity (middle right panel), and salinity (lower right panel). The solid red line in each plot corresponds to a perfect (i.e., 1:1) relationship between the primary and duplicate samples; the dashed lines correspond to a 10 or 20% coefficient of variation (blue and black lines, respectively). The majority of duplicates (between 60 and 94%) fall within a coefficient of variation of 20% (in the case of log-transformed FIB) and 10% (in the case of physical measurements). A coefficient of variation of 10 to 20% is well within the range expected for these analytes.

Comparison to Water Quality Standards
Most of the FIB measurements are well below the single-sample standards for TC (10,000 MPN/100 mL), FC (400 MPN/100 mL), and ENT (104 MPN/100 mL) (see % Single-Sample Exceedence (SSE) columns in Table 2). The exception to this rule were ENT measurements conducted during the Dunes II study, which exceeded the ENT single-sample standards between 6 and 14% of the time, depending on the sampling site category (Table 2). With the exception of the Dunes II and III studies, the geometric means of FIB fall below the geometric mean standards for TC (1,000 MPN/100 mL), FC (200 MPN/100 mL), and ENT (35 MPN/100 mL) (see columns labeled Geometric Mean in Table 2). During Dunes II, the geometric mean standard for TC was exceeded at marina, storm drain impacted, channel, and lagoon samples sites; during Dunes III the geometric mean standard for TC was exceeded at channel sites (although the geometric mean at storm drain impacted sites was > 900 MPN/100ml) (Table 2).

Vertical Stratification.
In general, there is not a significant difference between the concentration of FIB in samples collected from the surface of the water column, and from 1 m below the surface (Table 3). In the two cases where a significant difference is evident (based on a Krusakal-Wallis test), the difference in the medians is small (factor two in the case of TC measured during the BYB I study, and approximately 10% in the case of EC measured during the BYB II study). For all practical purposes, FIB pollution in Newport Bay is mixed down to a depth of at least 1 m.

Site-to-Site and Study-to-Study Variability.
The single-sample exceedences and geometric means of FIB are nearly the same across site categories (i.e., Marina, Channel, Storm Drain Impacted, Lagoon) (Table 2 and Fig. 4). Exceptions to this rule include:

> (1) The BYB II study, in which samples collected adjacent to storm drains (particularly along the west wall of the marina) had elevated concentrations of TC and ENT (see third row of color panels in Fig. 4). When comparing the results of the BYB I and II studies, it should be noted that storm drain sites along the walls of the BYB marina were not sampled during the BYB I study (sampling sites sampled during each study are indicated in Fig. 1).

> (2) The Dunes II study in which samples collected in the channel region (and along the eastern shoreline of the lagoon) had elevated concentrations of ENT (see fourth row of color panels in Fig. 4).

If the marinas were the primary source of contamination in Newport Bay, one might expect that the concentration of FIB would be highest in samples collected from the two marinas, and lower at the channel sites outside of the marinas, contrary to the trends evident in Fig. 4 and in Table 2.

While the concentration of FIB exhibits relatively little site-to-site variability, significant study-to-study variability is evident. The highest single-sample exceedence rates and

geometric means occurred during the Dunes II study; approximately 10% of all samples exceeded the single-sample standard for ENT during this particular study (Table 2). The Dunes II study had the shortest antecedent dry period (2 days, see Table 1), and the lowest recorded salinity and pH values (Table 2 and Fig. 4). Collectively, these observations suggest a potential connection between surface water runoff (which has relatively low salinity and pH, compared to ocean water) and FIB impairment in Newport Bay. It is interesting to note that Dunes II and Dunes III were carried out during relatively high-use periods in the marina. However, as documented below, the relationship between FIB concentrations, salinity, and tidal flow implicates surface water runoff--not boats--as the source of the FIB signal in the Bay.

Correlations between FIB and Salinity
To explore the potential link between runoff and FIB, Spearman Rank correlation coefficients were computed between FIB and salinity (Fig. 5). Spearman Rank correlation coefficients were used because they are non-parametric statistical parameters; i.e., they do not assume any particular statistical distribution of the data. FIB concentrations in the water column were strongly negatively correlated with salinity during the Dunes II study. Weaker negative correlation between FIB and salinity is also evident in several other cases, including:

> (1) Sampling sites located near storm drains during the BYB II study (third row of color panels in Fig. 5).

> (2) TC concentrations measured at all sites during the first BYB study and during the Dunes III study (first and fifth rows of Fig. 5).

A negative correlation between FIB and salinity--as observed in many cases at both the BYB and Dunes field sites--is consistent with a runoff source for these organisms.

III. C. Observations of Sediment-Associated FIB
Question: *How are FIB in the sediment of the BYB and Dunes marinas (and surrounding areas) distributed in space? How do the sediment concentrations compare with the concentration of bacteria in water just above the sediment bed? Are the sediments a reservoir, and perhaps even a source, of FIB in Newport Bay?*
Answer: *The concentration of FIB in sediments exhibits relatively little site-to-site variability, but significant study-to-study variability. The highest sediment concentrations were observed during the second Dunes study which, as described earlier, also had anamolously high bacterial concentrations in the water column. During the second Dunes study, the concentration of FIB in the sediment was so high that resuspension of sediments, for example by tidal flow, could have contributed to contamination of the water column. However, several lines of evidence indicate that the sediments are a net sink, not source, of FIB in Newport Bay.*

Reproducibility.
Measurements of FIB in the primary and duplicate sediment samples are compared in Fig. 3 (upper right panel). The majority of duplicates (between 75 and 84%) fall within a

coefficient of variation of 20% (for log-transformed FIB sediment concentrations), well within the range expected for these analytes.

Site-to-Site and Study-to-Study Variability.
As with the water column results presented in the last section, the concentration of FIB in the sediment exhibits significant study-to-study variability (at least for the two studies represented here), and relatively less site-to-site variability (Fig. 6 and Table 4). Concentrations of FIB measured in the sediment were at least one order of magnitude higher during the Dunes II study (geometric means in the range 10^3-10^4 for TC, 10^1-10^2 for EC, and 10^2-10^3 for ENT, all MPN/100 g of sediment), compared to the Dunes III study (geometric means in the range 10^0-10^1 for TC and EC, and 10^1-10^2 for ENT, all MPN/100 g of sediment) (Fig. 6 and Table 4).

The concentration of FIB in the sediment appears to be fairly constant across sites, with perhaps slightly higher concentrations of TC, and lower concentrations of ENT, in the lagoon sediments (Fig. 6, Table 4). Sediment concentrations of EC and ENT are somewhat elevated along the eastern shore of the lagoon, consistent with historical FIB water column data which indicate that that area is a consistent "hot spot" of FIB pollution (Pednekar et al., 200X). There is no obvious correlation between the concentration of FIB measured in the sediments, and the concentration of FIB measured in the water column just above the sediment bed (Fig. 6, Table 4). In particular, there are many examples where the concentration of FIB in the sediment are relatively high, but the concentration of FIB in the water above the sediment bed are relatively low; the opposite pattern (i.e., sediment concentrations low, above bed concentrations high) is also apparent in Fig. 6.

The sediment and above-bed water column data presented above suggest that a complex relationship exists between stormwater runoff, and the concentration of FIB in the water column and sediments. The antecedent dry period was only 2 days in the case of the Dunes II study (when the sediment and water column FIB concentrations were anomalously high) compared to 29 days for the Dunes III study (when the FIB concentrations in the water column and sediments were lower). Stormwater runoff entering the Bay may act to increase the concentration of FIB in the sediment by increasing the load of bacteria fluxing into the sediment from the water column, and/or by creating environmental conditions (nutrient status, temperature, salinity, pH, etc.) more favorable for bacterial re-growth in the sediment. Whatever the mechanism, once sediments end up harboring high concentrations of FIB, they represent a potential pathway for the repeated contamination of the water column by, for example, tidally driven sediment resuspension events (Sanders et al., 200X).

In summary, sediments in Newport Bay appear to be a reservoir of FIB, although the magnitude of that reservoir appears to depend strongly on time since the last rain event (antecedent dry period). While sediments may episodically contribute to FIB impairment in Newport Bay, they do not appear to be the sole source of impairment based on the following observations: (1) If water column impairment originated solely from resuspended sediments, the concentration of FIB in water samples collected just above

the bed should correlate with the concentration in the sediment samples, contrary to observations. (2) During the Dunes II study, the concentration of FIB in the water column was highest during the falling phase of the tide when salinity was dropping (data not shown). If sediment resuspension was the primary cause of impairment, FIB concentrations in the water column should peak during periods of high flow velocity, regardless of whether the tide is rising or falling, contrary to observations. (3) During the Dunes II study, the concentration of FIB in the water column at all sites was strongly negatively correlated with salinity (see Fig. 5). This observation is consistent with the idea that surface water runoff, not sediment resuspension, is a primary source of FIB in the Bay.

IV. Conclusions

The data described above shed light on the spatial and temporal variability of FIB concentrations in the water column and sediment at two marinas (and adjacent areas) in Newport Bay. Overall, the results do not support the idea that the two marinas studied here--the BYB and Dunes marinas--are significant sources of FIB contamination in Newport Bay, at least for the period of time encompassed by the five experiments. Instead, surface water runoff (both dry weather flows at sites located near storm drains, and storm water flow at all sites) appears to be a major source of FIB in the marinas and surrounding channel areas. Specific conclusions derived from current monitoring, water column testing, and sediment testing, are outlined below.

Data from the in situ measurements of current velocity, temperature, and salinity support the following conclusions:

- Currents at the BYB and Dunes study sites are strongly forced by the tides. Because of the sinuous nature of Newport Bay, during rising tides water flows in an westerly direction at the BYB site and in an easterly direction at the Dunes site. During falling tides water flows in an easterly direction at the BYB site and in a westerly direction at the Dunes site.
- Peak tidal flow velocities are approximately 10 cm/s in the channel outside of the BYB marina, and 50 cm/s in the channel outside of the Dunes marina.
- During rising tides, salinity increases and temperature decreases at the Dunes study site. The same pattern occurred during the second BYB study; however, temperature and salinity recorded during the first BYB study exhibited little/no tidal signature.

Data from the water column studies support the following conclusions:

- The water column concentration of FIB at the two field sites is generally well-mixed down to a depth of 1m.
- The geometric mean of FIB in water samples collected from the marina, channel, and storm drain sites follow the trend TC>>EC ENT. The exception is the Dunes III study for which the trend is TC>>EC>ENT.
- The majority of water samples did not exceed the single-sample standards for TC (10,000 MPN/100 mL), FC (400 MPN/100 mL), and ENT (104 MPN/100 mL).

- With the exception of the Dunes II and III studies, the geometric means of FIB in the water column were below the geometric mean standards for TC (1,000 MPN/100 mL), FC (200 MPN/100 mL), and ENT (35 MPN/100 mL). In the case of the Dunes II and III studies, the geometric mean standard was exceeded for TC only.
- With the exception of the BYB II study, the concentrations of FIB in the water column are relatively constant across site category (i.e., Marina, Channel, Storm Drains). During the BYB II study, sites located near storm drains (particularly along the west wall of the BYB marina) had elevated concentrations of TC, EC, and ENT.
- The concentration of FIB in the water column exhibited significant study-to-study variability that appears to be related to the elapsed time since the last storm (antecedent dry weather period). The highest FIB concentrations were recorded during the Dunes II study for which the antecedent dry weather period was only 2 days.
- FIB concentrations in the water column were negatively correlated with salinity during the Dunes II study, implicating storm runoff as the primary source of FIB in this particular case. The correlation between FIB and salinity was generally much weaker during the other four studies, with the exception of sampling sites located near storm drains.
- Overall, these data are not consistent with the idea that the BYB and Dunes marinas are significant sources of FIB impairment in Newport Bay. Evidence for this conclusion includes:

  (1) The concentration of FIB in samples collected from the marina sites were generally lower than the concentration of FIB in samples collected from sites outside of the marina (e.g., channel sites).

  (2) The concentration of FIB was negatively correlated with salinity during the one study (the Dunes II study) for which a significant fraction (approximately 10%) exceeded the single-sample standards.

  (3) In situ measurements indicate that low salinity water flowed into the study site during falling tides, strongly implicating storm runoff from Upper Bay as the cause of FIB impairment during the Dunes II study.

Data from the sediment (and above-bed water sampling) studies support the following conclusions

- Concentrations of FIB measured in the sediment were at least one order of magnitude higher during the Dunes II study (geometric means in the range 10^3-10^4 for TC, 10^1-10^2 for EC, and 10^2-10^3 for ENT, all MPN/100 g of sediment), compared to the Dunes III study (geometric means in the range 10^0-10^1 for TC and EC, and 10^1-10^2 for ENT, all MPN/100 g of sediment)
- The FIB sediment concentrations measured during the Dunes II are sufficiently high that resuspension of sediments (e.g., by tidal flow) could, in principle, contribute to FIB impairment in the Bay.

- The concentration of FIB in the sediment exhibits relatively modest site-to-site variability, but significant study-to-study variability. The concentration of FIB in the sediment is highest during the study (the Dunes II study) that had the highest water column concentration of FIB.
- The concentration of FIB in water samples collected just above the sediment bed show no obvious correlation to the concentration of FIB in the sediment.
- Overall, while sediments may contribute to FIB concentrations in the water column, the data presented in this report do not support the idea that FIB impairment in the Bay is caused solely by the resuspension of contaminated sediment. Evidence for this conclusion includes:

1. If sediment resuspension was the primary cause of FIB impairment then the concentration of FIB in water samples collected just above the bed should be correlated with the concentration of FIB measured in the sediment, contrary to the trend reported here.

2. During the Dunes III study, the concentration of TC in the sediment was relatively low, yet the concentration of TC in the water column was relatively high. Indeed, the Dunes III study was one of only two studies where the geometric mean of TC measured in all water samples exceeded the geometric mean standard for this organism.

3. During the Dunes II study, the concentration of FIB was highest during the falling phase of the tide when runoff Upper Newport Bay advects into our study area. If sediment resuspension was the primary cause of FIB impairment in the Bay, FIB concentrations should peak during periods of peak velocity, regardless of whether the tide is rising or falling, contrary to the trend reported here.

4. During the Dunes II study, the concentration of FIB in the water column exhibited a strong negative correlation with salinity (i.e., the FIB concentrations were highest in parcels of water with low salinity). The strong negative correlation with salinity is not consistent with the idea that FIB impairment is caused primarily by sediment resuspension.

V. References

1. Boehm, A.B., S.B. Grant, J.H. Kim, S.L. Mowbray, C.D. McGee, C.D. Clark, C.M. Foley, D.E. Wellman (2002) "Decadal and shorter period variability of surf zone water quality at Huntington Beach, California", <u>Environmental Science and Technology</u> **36**:3885-3892.

2. Boehm, A. J. Fuhrman, R.D. Mrse, S.B. Grant (2003) "A tiered aproach for identification of human fecal pollution source at a recreational beach: Case study at Avalon Bay, Catalina Island, California", <u>Environmental Science and Technology</u>, **37**:673-680.

3. Kim, J.H. and S.B. Grant (2004) "Public mis-notification of coastal water quality : A probabilistic analysis of posting errors at Huntington Beach, California", <u>Environmental Science and Technology</u> **38**:2497-2505.

4. Reeves, R.L., S.B. Grant, R.D. Mrse, C. Oancea, B.F. Sanders, and A.B. Boehm (2004) "Scaling and management of fecal indicator bacteria in runoff from a coastal urban watershed in southern California", <u>Environmental Science and Technology</u>, **38**:2637-2648.

5. Kim, J.H., S.B. Grant, B.F. Sanders, C.D. McGee, J.L. Largier (2004) "Tidal dynamics and mass budgets of fecal pollution in the surf zone: case study at Huntington State Beach, California" <u>Environmental Science and Technology</u>, **38**:2626-2636.

6. S.B. Grant, Kim, J.H., B. Jones, S. Jenkins (200X) "Surf zone entrainment, long-shore transport, and human health implications of fecal pollution from tidal outlets", submitted.

Table 1: Timing and general features of the five marina studies.

Study	Timing	Antecedent Dry Weather Period	Number of Sites
Balboa Yacht Basin I	7/26 16:00-7/29 4:00, 2002	67 days	11
Dunes Marina I	9/20 16:00-9/23 4:00, 2002	123 days	11
Balboa Yacht Basin II	11/22 16:00-11/25 4:00, 2002	6 days	27
Dunes Marina II	4/18 16:00-4/21 1:00, 2003	2 Days	36
Dunes Marina III	8/29 16:00-9/1 1:00, 2003	29 Days	24

Table 2. Average physical and FIB measurements on water samples, arranged by study and site category.

Study	Total Coliform (MPN/100 mL)		E. Coli (MPN/100 mL)		Enterococcus (MPN/100 mL)		pH	Salinity (ppt)	Turbidity (NTU)
Balboa Yacht Basin I	Number of Samples	% SSE[a] / Geometric Mean	% SSE[a]	Geometric Mean	% SSE[a]	Geometric Mean	Average	Average	Average
Overall	458	0	279	<1	15	2	11	8.15	32.5	2.09
Marina	250	0	295	1	16	1	10	8.15	32.5	1.78
Channels	208	0	261	0	14	3	11	8.16	32.5	2.46
Dunes Marina I									
Overall	462	0	124	0	11	1	11	8.06	30.9	3.69
Marina	210	0	113	0	11	0	10	8.06	30.9	3.16
Channels	252	0	135	0	11	2	11	8.07	31.0	4.13
Balboa Yacht Basin II									
Overall	815	1	177	<1	12	3	12	8.00	30.2	1.94
Marina	292	0	132	0	12	0	10	8.02	30.3	1.80
Channels	169	1	199	0	12	0	10	8.01	30.2	2.46
Storm Drains	354	2	213	1	13	7	15	7.99	30.1	1.81
Dunes Marina II									
Overall	1434	1	1292	<1	19	10	25	7.97	29.9	2.38
Marina	358	0	1257	0	18	9	26	7.96	30.0	2.04
Channels	479	0	1201	0	20	14	27	7.97	30.3	2.13
Storm Drains	120	0	1549	0	18	8	30	7.94	29.6	1.85
Lagoon	477	2	1355	1	21	6	21	8.00	29.6	3.01
Dunes Marina III									
Overall	956	1	969	2	51	<1	10	8.11	32.4	2.06
Marina	359	1	864	3	55	1	11	8.11	32.3	1.75
Channels	477	0	1076	1	48	0	10	8.12	32.4	2.39
Storm Drains	120	1	906	2	49	0	10	8.08	32.3	1.66

[a] Percentage of samples that had fecal indicator bacterial concentrations as high as or exceeding the California single sample standard.

Table 3: Median concentration of fecal indicator bacteria measured in samples collected at the surface and 1 m below the surface (all concentrations in units of MPN/100 mL)

		BYB I	Dunes I	BYB II	Dunes II	Dunes III
TC	surface	*410	135	161	1396	1236
	1m	216	121	160	1401	1334
EC	surface	10	9	*9	20	73.5
	1m	10	9	10	20	63
ENT	surface	9	9	9	20	9
	1m	9	9	9	20	9

*Median concentration significantly different than 1 meter samples Krusakal-Wallis (P<0.05)

Table 4. Average Physical and FIB measurements on Sediment and Bed samples arranged by study site and category

Study	Total Coliform (MPN/100g Dry Sediment or MPN 100/mL Water)				E. coli (MPN/100 g Dry Sediment or MPN 100/mL Water)				Enterococcus (MPN/100 g Dry Sediment or MPN 100/mL Water)				pH	Salinity (ppt)	Turbidity (NTU)
Dunes Marina II	N	Geometric Mean (CI)[a]	N	Geometric Mean (CI)	N	Geometric Mean (CI)[a]	N	Geometric Mean (CI)[a]	N	Geometric Mean (CI)[a]	N	Geometric Mean (CI)[a]	Average (SD)[b]	Average (SD)[b]	Average (SD)[b]
	Sediment[c]		Water Above Sed. Bed		Sediment[c]		Water Above Sed. Bed		Sediment[c]		Water Above Sed. Bed				
Overall	55	2250.8 (1473.7/890.6)	85	1996.4 (464.4/376.8)	55	38.3 (24.9/15.1)	85	23.23 (4.7/3.9)	56	163.6 (119.6/69.1)	85	42.8 (14.3/10.7)	8 (0.7)	31.4 (1.0)	10.9 (20)
Marina	24	1650.7 (1642.4/823.3)	32	2318.3 (892.6/644.5)	24	30.2 (26.8/14.2)	32	25.6 (8.4/6.3)	26	179.9 (204/95.6)	32	73.0 (41.9/26.6)	8 (0.04)	31.5 (1.1)	8.9 (8.0)
Channels	22	1811.3 (2230.6/999.6)	29	1954.3 (914.4/623)	22	36.3 (43.2/19.7)	29	22.6 (10.2/7)	21	251.2 (421.3/157.4)	29	52.0 (32.3/20)	8 (0.03)	31.6 (1.0)	16.0 (27.4)
Lagoon	9	8751.8 (22352.5/6289.3)	24	1678.3 (788.4/536.4)	9	82.1 (374.4/67.3)	24	21.1 (7.3/5.4)	9	45.7 (81.3/29.2)	24	16.5 (7.6/5.2)	7.8 (1.5)	31.3 (0.9)	11.1 (20.5)
Dunes Marina III							Water Above Sed. Bed								
Overall	60	8 (1.4/1.2)	71	196.7 (58.3/45)	60	6.8 (0.8/0.7)	71	17.9 (3.9/3.2)	60	35.6 (18.3/12.1)	72	10.6 (1.3/1.1)	8.1 (0.05)	33 (1.5)	18.8 (34.5)
Marina	39	8.6 (1.8/1.5)	42	237.6 (106.4/73.5)	39	7.1 (1/0.8)	42	17.9 (5.7/4.3)	39	44.8 (34.4/19.5)	42	11.4 (2.3/1.9)	8.1 (0.04)	33 (2)	25.4 (42.6)
Channels	21	7.1 (2.2/1.7)	29	149.7 (57.3/41.4)	21	6.2 (1.3/1.1)	29	17.9 (5.7/4.3)	21	23.3 (15.4/9.2)	30	9.6 (0.7/0.7)	8.1 (0.05)	33 (0.3)	9.8 (15)

[a] Confidence Interval (+/-)
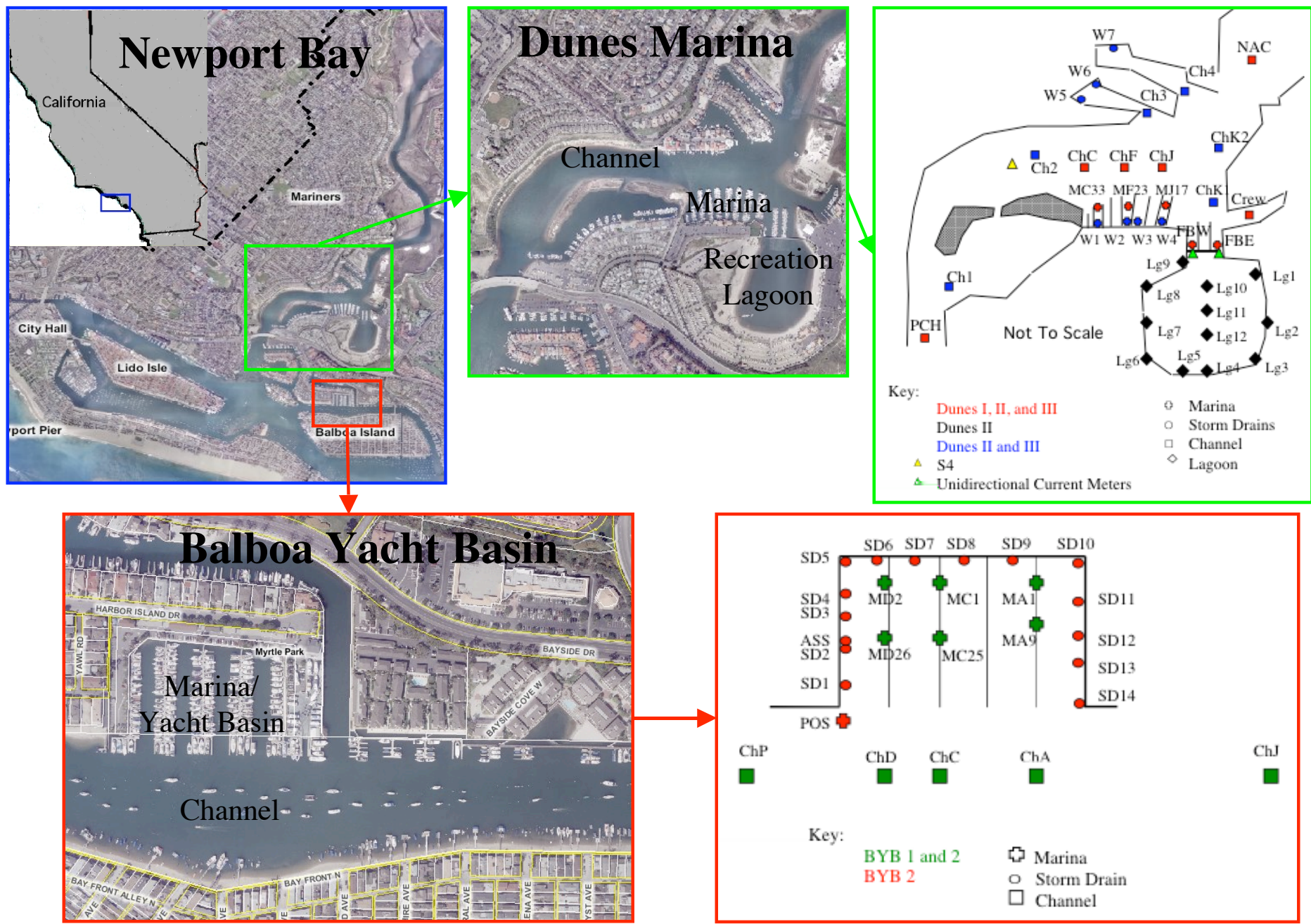[b] Standard Deviation
[c] all Sediment Values

Figure 1: Aerial site layout for Newport Bay Studies.
Aerial photographs obtained from: http://www6.city.newport-beach.ca.us/website/nb_map/viewer.htm.
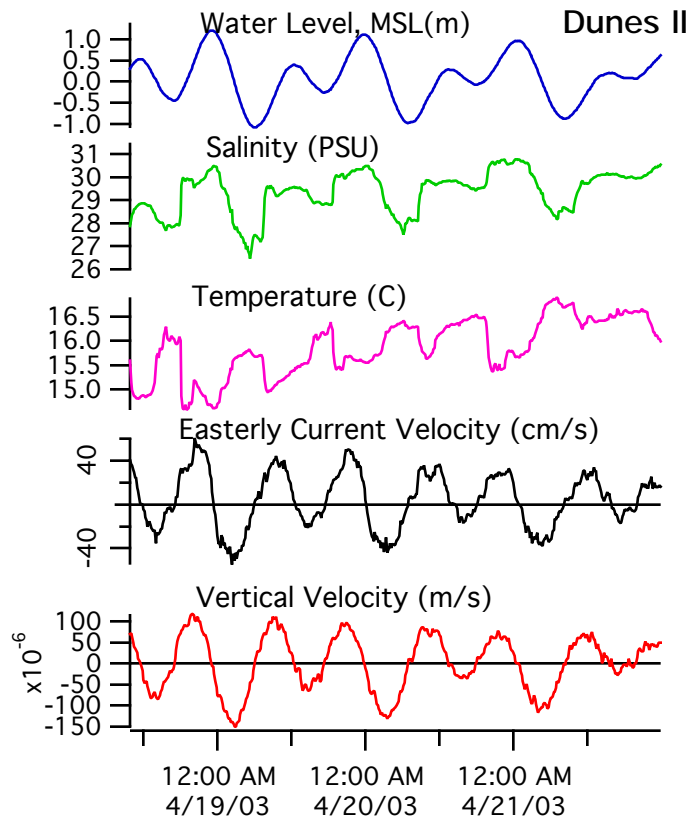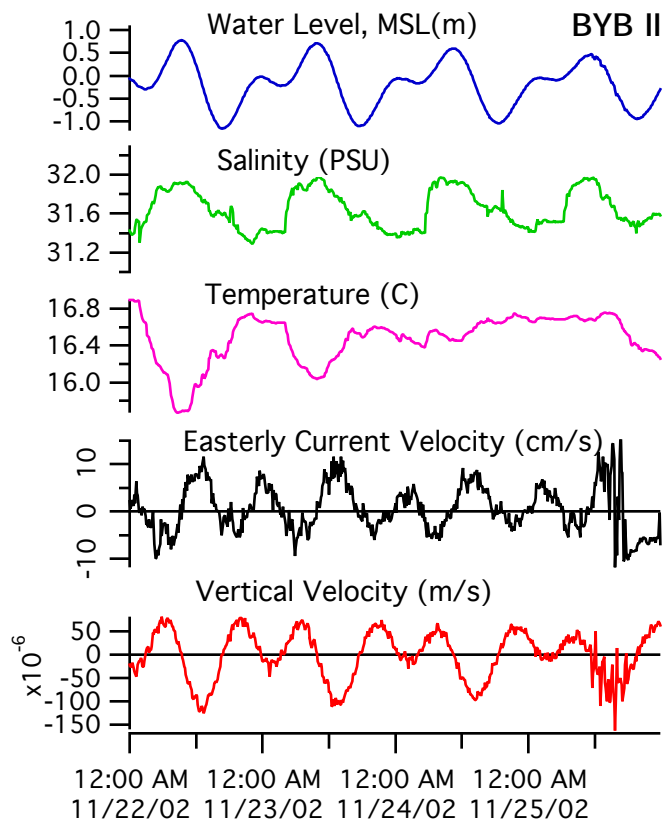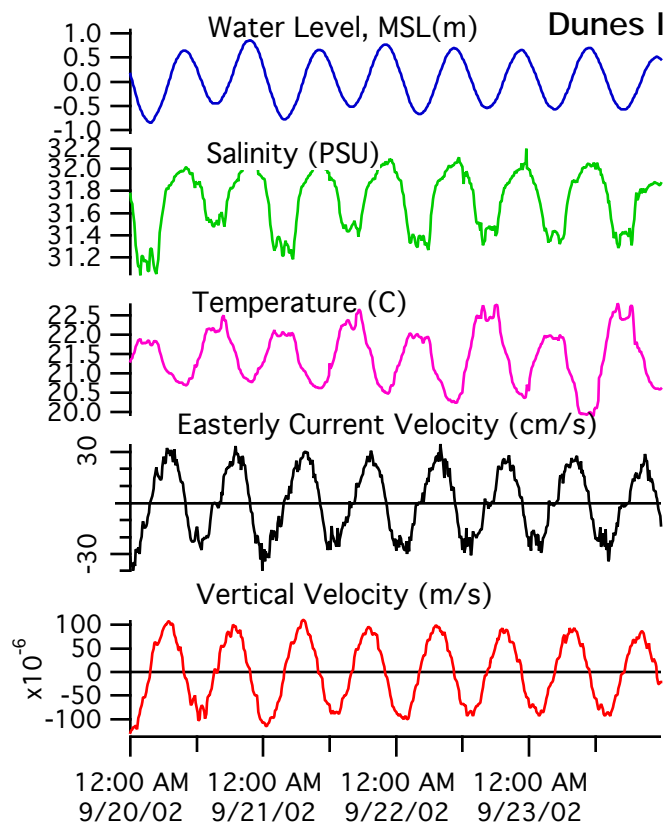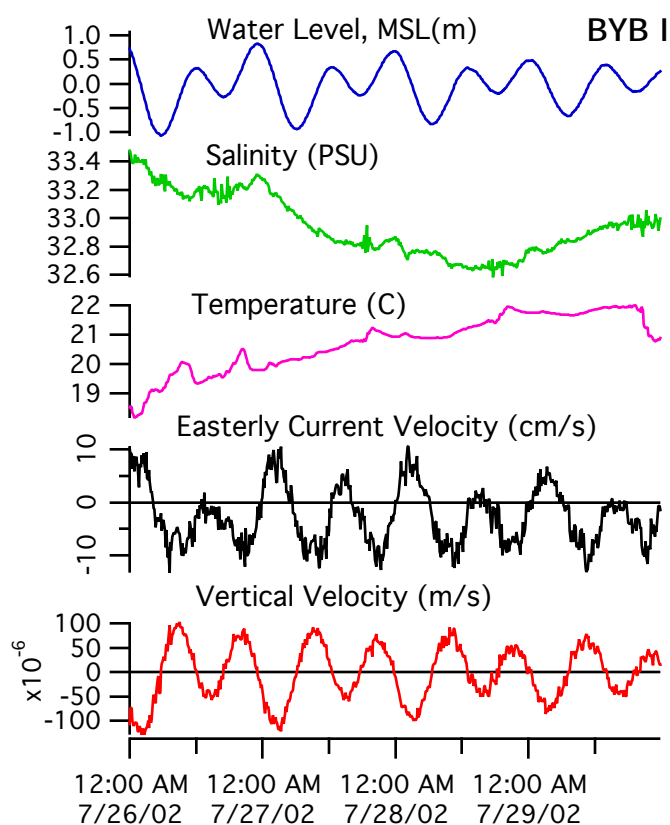
Figure 2. Time series plots of water level (top panel), salinity (second panel), temperature (third panel), eastly current velocity (fourth panel), and vertical velocity (fifth panel).
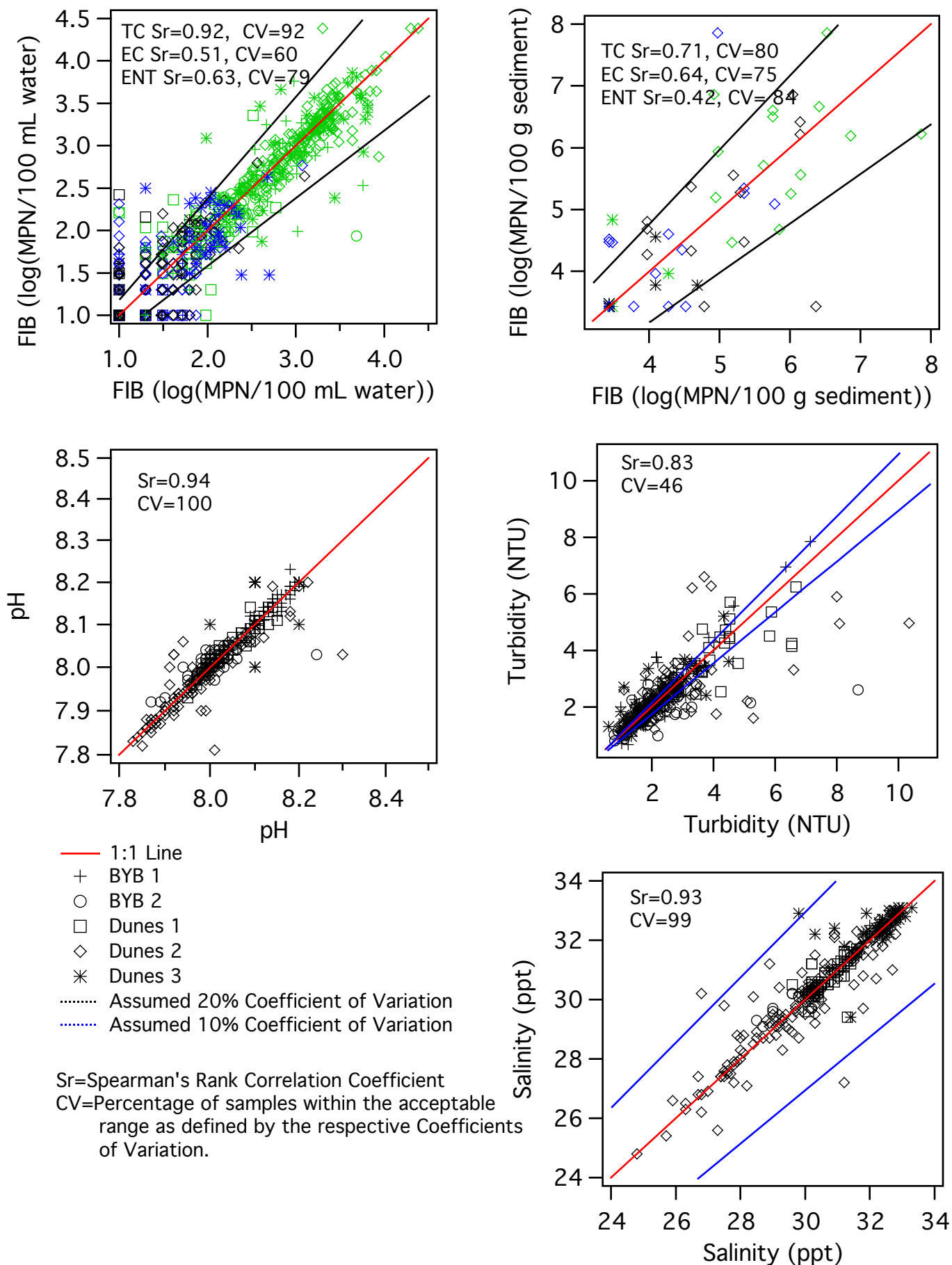
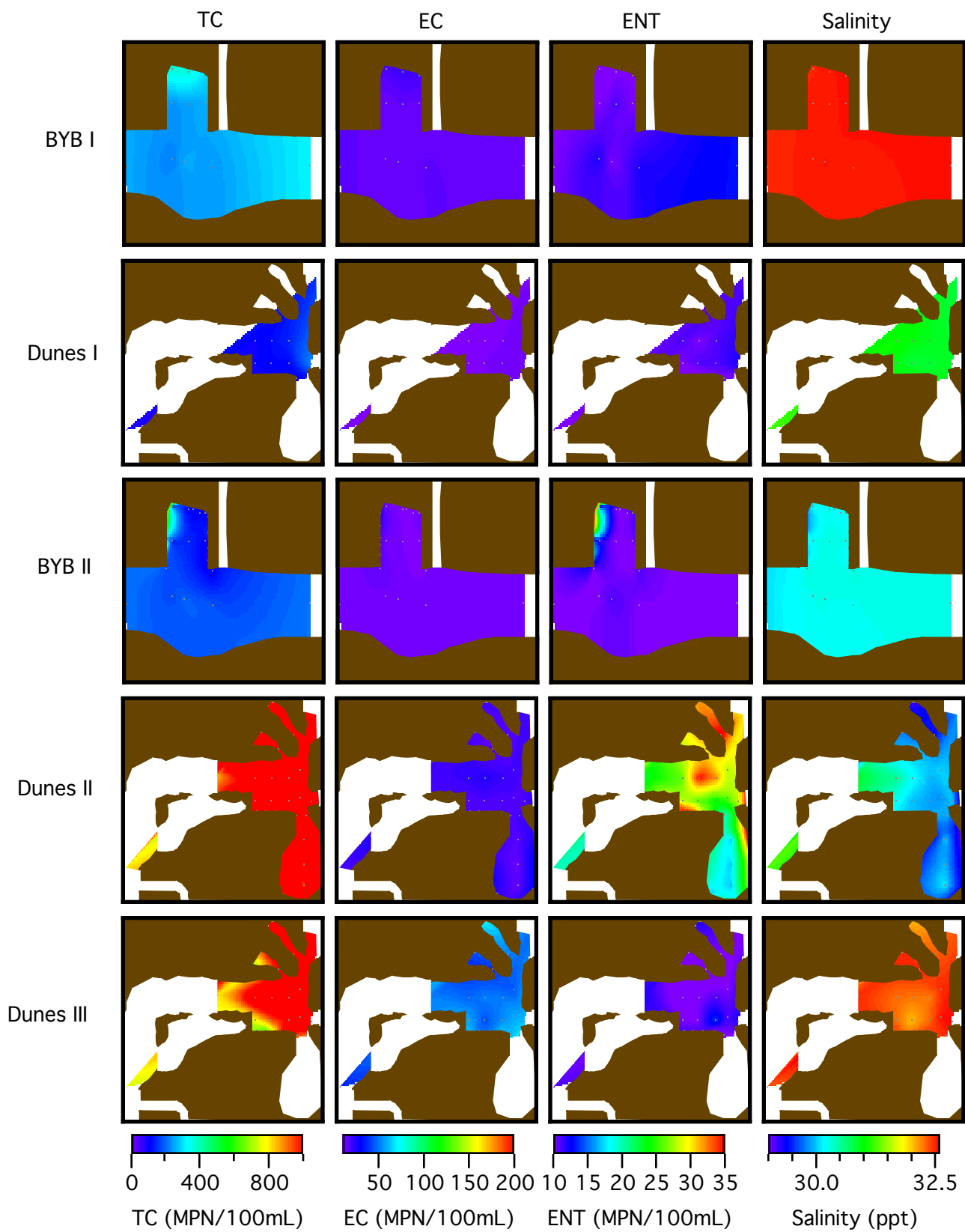Figure 3. Comparison of test results from duplicate samples.

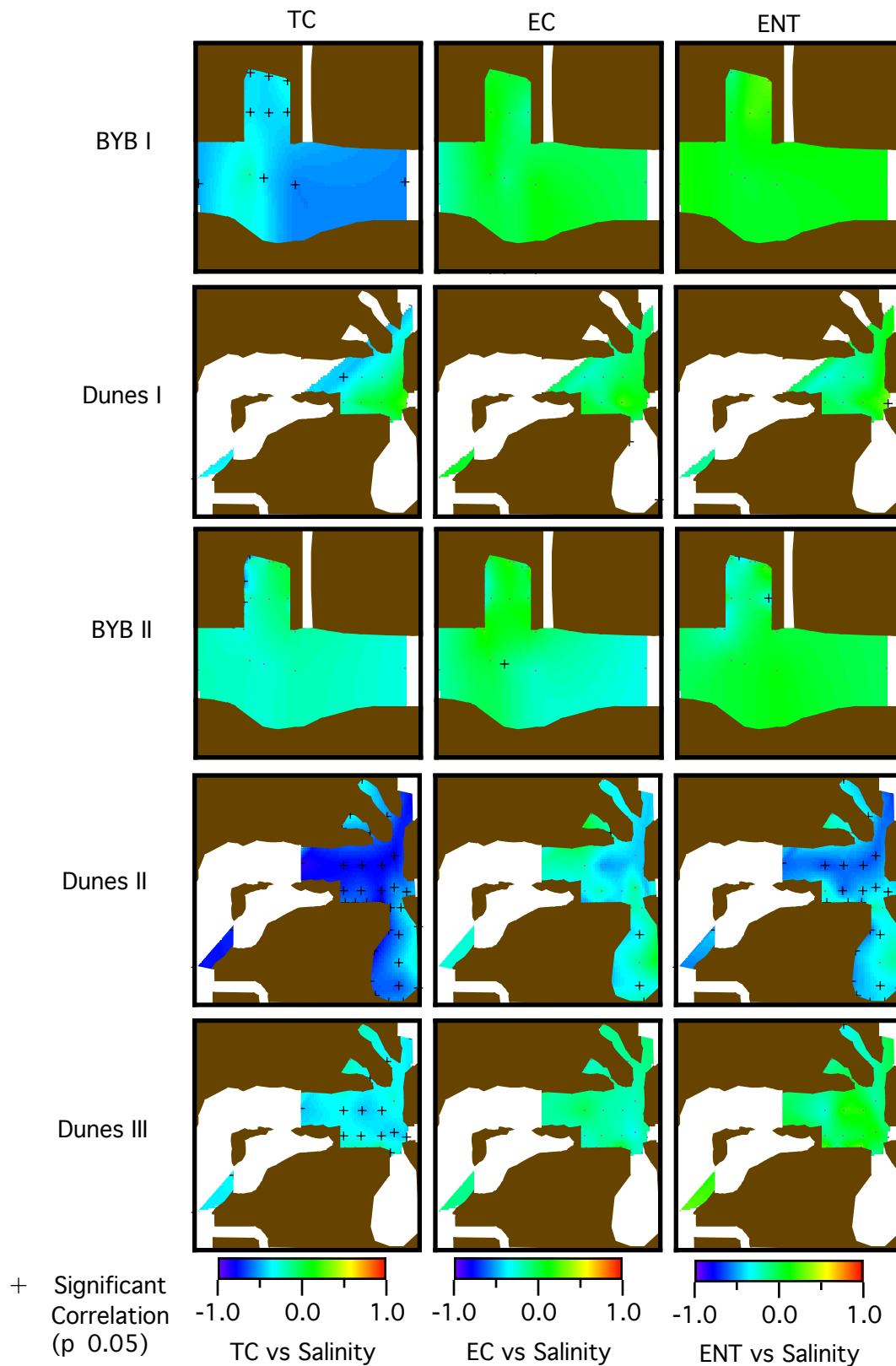Figure 4. Color contour plots of the geometric mean of fecal indicator bacteria and average salinity.

Figure 5. Color contour plots of Spearman Rank correlations between fecal indicator bacteria and salinity . Sampling stations with statistically significant correlations (p 0.05) are designated with (+).

Log(FIB) MPN/100g
Dry Sediment

Log(FIB) MPN/100mL
Water Above Sediment Bed

Dunes II   Dunes III   Dunes II   Dunes III

TC

3   4   5   6   7

1.0   2.5

EC

3.0   5.0

1.0   2.0   3.0

ENT
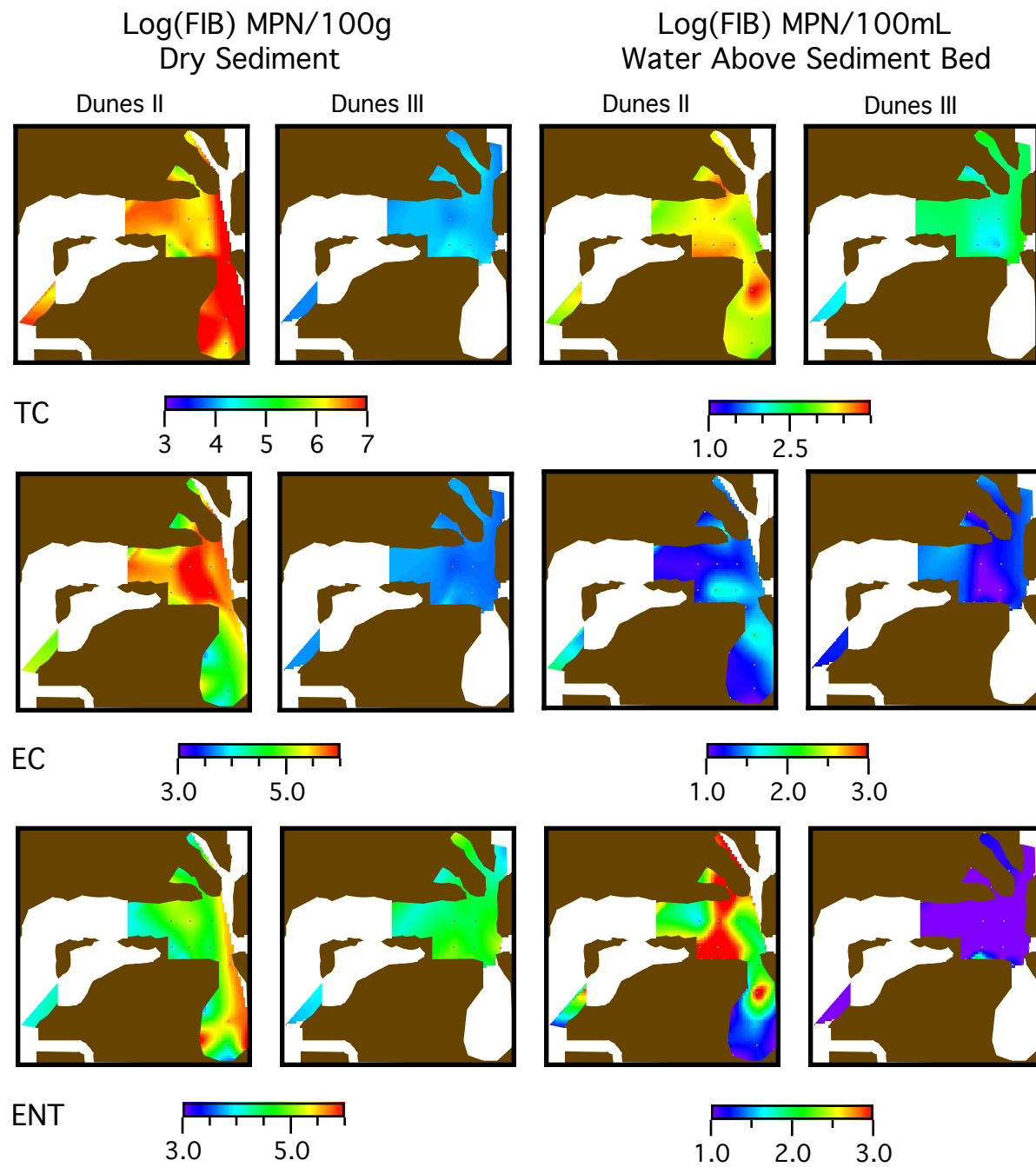
3.0   5.0

1.0   2.0   3.0

Figure 6. Spatial distribution of fecal indicator bacteria in the sediment (and in the water above the sediment bed) during the Dunes II and III studies.